A Glass Half Full

By Morton Satin

In Samuel Taylor Coleridge's *Rhyme of the Ancient Mariner*, the old sailor narrates the woes of his recent travels, "Water, water, everywhere, Nor any drop to drink." He may have been describing the account of a mythical voyage, but his words reflect one of our future's greatest challenges—access to quality water. More than 95 percent of the world's water is sea or brackish water that is unsuitable for either drinking or agriculture. While the remaining five percent of freshwater has remained stable over the eons, the world's population has increased astronomically, giving us little choice but to make major adjustments to the way we access and manage our water resources.

More than a third of the world's population lives in regions facing significant water shortages and during the next half-century, the amount of water needed to serve our rapidly expanding needs is likely to double. Since 1950, the amount of agricultural land under irrigation has tripled, leading to Asia's Green Revolution—a technological tour de force that improved the lives of billions. However, a large part of the same region (including India, China, central and west Asia) have reached the limits of their easily available water supplies.

The US also faces severe challenges in meeting its future water needs that cannot be managed by simply relying on water conservation or improving the efficiency of water use. Of course, we have to protect and improve the quality of all our current water resources, but we have little choice but to develop and make available additional water resources to serve the needs of our growing population and the agricultural production needed to sustain it.

Over the next 20 years, it is highly likely that many areas of our country will face dramatic changes in the availability, quality, disposal and regulation of our water supplies. There are no new sources of conventional freshwater. Everything we have is already allocated to specific uses. On the other hand, there are unlimited supplies of sea, brackish and impaired groundwater available throughout the country. The haste with which we can access these new supplies will largely depend upon the political will to accept the reality of a challenging new world and the policies to aggressively support the establishment of cost-effective technologies to convert these sources into water of the desired quality.

In a 1988 report, the Congressional Office of Technology Assessment suggested that large scale desalination could find application in treating impaired groundwater, be it runoff from mines, agriculture, landfills or storage tanks. In 2002, Congress authorized the Energy and Water Development Appropriation Bill wherein it recognized, "... that effective desalination cost reduction is the key to wider use of desalination for improving the quality of life in water scarce regions."

Impaired waters are the result of natural and human processes. In fact, human activity, such as mining, agriculture or water treatment account for a small portion of water impairment. Contrary to what many environmental activists believe, as much as 80 percent of the salt and other minerals found in surface and groundwater is the result of simple, natural erosion. However, intensive use of waters for municipal and agricultural purposes does increase the variety of contaminants, such as detergents, found in surface and groundwater and is a matter of growing concern.

There is no 'best method' of desalination. A wide variety of technologies effectively extract freshwater from salty water, producing one stream with a low concentration of salt and another with a high concentration of residual salts. Most of these technologies rely on either distillation or membranes to separate salts from the product water.[1] The selection of a particular desalination process will depend on site-specific conditions, such as the salt content of the water, the quality of water needed by the end user and the overall economics.

The price of desalination technologies has been dropping at a rate of about four percent per year. While this may not seem impressive at first glance, it must be remembered that energy is a key component of these technologies and the price of energy in the last few years has been on a rollercoaster ride. When this is factored in, the steady drop in desalination costs is, in fact, quite impressive. Desalination using carbon nanotube membranes could significantly reduce the cost of removing salt from waters. It has been speculated that the new membranes, developed at the Lawrence Livermore National Laboratory, could reduce desalination costs by as much as 75 percent, compared to the reverse osmosis (RO) methods that are in use today.[2]

One of the areas of greatest desalination concern is the disposition of waste concentrates left over from processing. In fact, disposal of concentrates is beginning to eclipse cost-effectiveness as the primary issue. This is one of the reasons that thermal and membrane technologies are often combined, so that the waste stream can be minimized. It is the goal of modern desalination technology to come as close to the ideal technology as possible—where the waste material will be disposed of as a solid while 100 percent of the water would be effectively recaptured for specific uses.

Membrane and filtration systems

Membranes and filters allow or prohibit the passage of certain ions and are thus well suited for the function of desalination. It is convenient to incorporate a filtration stage prior to the membrane processing in order to prevent fouling by removing contaminants that might affect the long-term functional life of the membranes. Because membranes play an important role in the separation of salts in natural dialysis and osmosis, these principles have been adopted in two commercially important desalting processes: electrodialysis and RO. Although they were originally used to desalinate brackish water, they are increasingly being applied to seawater. Currently, some form of electrodialysis or RO accounts for more than half of all desalination capacity. Table 1 lists the characteristics of major filtration and membrane systems in common use today.

Table 1. Characteristics of major filtration and membrane systems

Type	**Common applications**
Microfiltration	Removal of suspended solids, microorganisms; MF membranes operate under lower pressures than UF of NF membranes
Ultrafiltration	Separation of complex organics, volatiles, viruses
Nanofiltration	Water softening; sulfate removal
RO	Salt removal in brackish and seawater
Electrodialysis	Salt removal in brackish water

RO uses pressure on salty solutions to force freshwater to move through a semi-permeable membrane, leaving the salt behind. RO can effect desalinated water recovery rates ranging from 30 to 85 percent of the volume of the input water (depending on the initial water quality, finished product requirements and the technology / membranes employed). RO membrane technology has been used for some of the largest new desalination plants in operation and under construction

Introduced over half a century ago, electrodialysis proved to be a cost-effective means of desalinating brackish water. Electrodialysis works on the principle that dissolved, ionized salts can move through engineered membranes towards electrodes with opposite electric charges, leaving the freshwater behind. A modification of this system involves periodic pole reversal in order to backflush lines and membrane stacks.

A new development for RO is the nanocomposite membrane made up of cross-linked polymers and nanoparticles designed to absorb water ions but repel all other contaminants. This latter characteristic is very significant because the ability to repel organics and microorganisms will lead to longer membrane life with lower maintenance requirements. This will result in a water purification process that is just as effective as current RO technology but with greater energy efficiency and a potential 25 percent cost saving.[3,4]

Thermal systems

Worldwide, about 40 percent of the world's desalinated water is produced by the thermal distillation of brackish or seawater. In its most rudimentary form water, at atmospheric pressure, is boiled at 100°C (212°F) and the salt-free condensate is collected. However, we have known for more than a century that we can distill water at a lower temperature in a vessel that is under a reduced pressure. If the pressure is reduced to 25 percent of the atmospheric pressure, the water will boil at 65°C (149°F) and if you further reduce the pressure to 10 percent of the normal atmospheric pressure, it will boil at only 45°C (113°F). This principle has been incorporated in a variety of 'multiple effect' processes whose purpose is to boil, distill or evaporate water.

Currently, the most widespread thermal method of desalination is the multi-stage flash (MSF) design, which has been in commercial use for more than 30 years. This process involves the use of distillation through several chambers. In the MSF process, each successive stage of the plant operates at progressively lower pressures. The feedwater is first heated under high pressure and is led into the first 'flash chamber', where the pressure is released, causing the water to boil rapidly resulting in sudden evaporation or 'flashing'.[5]

This flashing of a portion of the feed continues in each successive stage, because the pressure at each stage is lower than in the previous stage. The vapor generated by the flashing is converted into freshwater by being condensed on the heat exchanger tubing that runs through each stage. The tubes are cooled by the incoming cooler feedwater. Generally, only a small percentage of the feedwater is converted into vapor and condensed. Multi-stage flash distillation plants have been in regular use since the late 1950s. In MSF, flashing occurs from the liquid, not on a heat-exchange surface, and minimizes the buildup of scale on heated surfaces, reducing a major maintenance problem.

Another technique for commercial desalination is multi-effect distillation (MED), widely used long before the MSF method. This process occurs in a series of vessels (effects) and uses the same principles of evaporation and condensation at reduced ambient pressure. In MED, a series of evaporator effects produce water at progressively lower pressures. Water boils at lower temperatures as pressure decreases, so the water vapor of the first vessel or effect serves as the heating medium for the second and so on. The more vessels or effects there are, the higher the performance ratio. Depending on the arrangement of the heat exchanger tubing, MED units could be classified as horizontal or vertical tube operations.[5]

Vapor compression distillation

Vapor compression distillation is another process that takes advantage of the principle of reducing boiling-point temperature by reducing the ambient pressure, but in this case, the heat for evaporating the water comes from the compression of vapor rather than from steam produced in a boiler. This technology is generally used for small- and medium-scale desalinating.[5] Vapor compression units use a compressor to create a vacuum, compress the vapor taken from the vessel and then condense it inside a tube bundle that is also in the same vessel, producing a stream of freshwater. As the vapor condenses, it produces freshwater and releases heat to warm the tube bundle. Salt water is then sprayed on the outside of the heated tube bundle, where it boils and partially evaporates, producing more freshwater.

Some of the more recent developments in thermal desalination systems are based upon improved heat transfer systems such as plates which have high-heat transfer coefficients compared to conventional shell-and-tube technologies.

Diffusion driven desalination

A new low-energy thermal process designed to use excess heat recovered from operations such as electric utility plants is diffusion driven desalination (DDD) developed at the University of Florida.[6] The water supply is drawn in and then pumped through a regenerative heat exchanger which is then sprayed into the top of a diffusion tower. The diffusion tower is filled with specific packing materials to enhance the water / air surface area. Air is blown through the bottom of the tower and becomes humidified. The humidified air goes to a direct-contact condenser where the freshwater is condensed.

Nuclear desalination

Nothing exemplifies the importance of recovering waste heat as a critical factor in future technologies more than the concept of nuclear desalination. It is generically defined as the production of water in a facility where a nuclear reactor is used as the source of energy (electrical and / or thermal) for the desalination process. The facility may be dedicated solely to the production of water, or may be used for the generation of electricity and the production of quality water, in which case only a portion of the total energy output of the reactor is used for water production. In either case, the notion of nuclear desalination is taken to mean an integrated facility in which both the reactor and the desalination system are located on a common site and energy is produced onsite for use in the desalination system.

The feasibility of integrated nuclear desalination plants has been proven with over 150 reactor-years of experience in Kazakhstan, India and Japan.[7] A reactor at Aktau, in Kazakhstan, produced up to 135 MWe of electricity and 80,000 m^3 / day of potable water over a period of 27 years. In Japan, 10 desalination facilities which were associated with pressurized water reactors operating for electrical power production yielded 1,000-3,000 m^3 / day of potable water each. Over 100 reactor-years of experience have accrued, originally with MSF, but now converted to a combination of MED and RO. In 2002, India set up a demonstration plant coupled to twin nuclear power reactors at the Madras Atomic Power Station, in southeast India. This project is a hybrid RO / MSF plant, the RO with 1,800 m^3 / day capacity and the higher-quality MSF with 4,500 m^3 / day.

In the US, a membrane desalination facility was linked to the Diablo Canyon Nuclear Power Plant in California. The water intake and outtake systems are shared between the plant's cooling water systems and the membrane plant resulting in about 4,500 m^3 / day of freshwater supplied to the plant. The plant efficiency is such that membrane elements have not been replaced for over 10 years. It is also worthwhile noting that nuclear power plants release negligible amounts of greenhouse gas emissions to the environment.[8]

In addition to these nuclear desalination programs, active initiatives in this technology are being carried out in Argentina, Canada, China, Egypt, France, Israel, Rep. of Korea, Libya, Morroco, Pakistan and Russia.[9,10]

The recognition that dependency on foreign oil is a growing threat to economic security has shaken policy makers and motivated them to consider meaningful strategies for future energy requirements. At least for the short term, nuclear energy holds among the best potentials to answer our energy needs. While there is no doubt that initial capital costs are high, the operating costs of make nuclear technology very competitive. The Chernobyl disaster notwithstanding (the result of a operator mismanagement and poor control rod design[11]), nuclear energy has an excellent safety record and is ideally suited for highly decentralized electricity production—a characteristic which also coincides with a good deal of our future groundwater desalination needs. Therefore, it makes sense to consider commercial-scale desalination of impaired groundwater and nuclear energy together. They are both imperatives we cannot ignore and the coincident alliance of these technologies is serendipitous.

In addition to developments in desalination processes *per se*, there have also been parallel developments in accessing of feedwater to supply processing plants. An excellent example of this is the Dana Point, Calif. ocean desalination project. Here a unique dual rotary slant well drilled under the ocean supplies the intake system and serves the dual purposes of feedwater supply and seawater intrusion control.[12] Among the advantages of this system are pre-treatment benefits, protection against red tides and better sea water intrusion control.

While coastal areas can easily access seawater for desalination, the rest of the country will have to access impaired groundwater and brackish water resources. A critical impediment to brackish groundwater desalination is the need for infrastructure and systems that provide for an environmentally acceptable means of disposal of the brine concentrate discharge. Where these issues have been solved, brackish groundwater desalination facilities have been successfully permitted. Examples include the El Paso / Fort Bliss (Texas) Desalination Facility which uses membrane filtration to reduce effluent concentrate discharge while their pilot research hopes to improve discharge efficiency using vibrating membranes.[13] California alone has more than 40 brackish groundwater-desalinating facilities (both RO and ion exchange desalting).

The *Rhyme of the Ancient Mariner* is a rather long poem and we always tend to quote that one stanza about the lack of potable water. Considering the current vitality and future potential of the desalination industry, perhaps we would be better off quoting the poem's very last line that speaks of a more optimistic future, "A sadder and a wiser man, He rose the morrow morn."

If we continue to tackle the water challenges we face with energy and optimism, we'll have "...every drop to drink!"

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Mort Satin is Director for Technical and Regulatory Affairs at the Salt Institute. Trained as a molecular biologist, Satin is a well-known executive and author with international experience in research, marketing and management. For 16 years, he directed the global Agro-Industry program at the Food and Agriculture Organization of the United Nations (FAO) in Rome, where he received international recognition for his work on the impact of technology on economic development. He developed several new food processes and received the only patents ever awarded to the United Nations System. Satin also served as the FAO liaison to the IAEA Chernobyl Committee. In 1989, while at FAO, he was nominated for the World Food Prize by the World Food Council. Satin retuned to North America as Executive Director of the International Agribusiness Management Association (a group of academics and CEO's representing > $700 billion in global sales). Satin has published over 250 articles on a wide range of food science, health, technology and agribusiness topics including a "Scenario on the Future of Food Science" for the Science Council of Canada. For the Asian Productivity Organization, Satin has spoken extensively on food safety, labeling, international certification, and other issues related to food technology and marketing. He has authored four text books in English and Spanish on the subjects of food safety, food history and irradiation and has a fifth book coming out this year "Death in the Pot: The Impact of Food Poisoning on History".

About the organization

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